THE CAINOZOIC SUCCESSION OF MASLIN AND ALDINGA BAYS, SOUTH AUSTRALIA

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Contents

SUMMARY

After a general description which includes the Pre-Tertiary Basement, the succession, its structure as shown by dip measurements, and the physiography of the area are discussed. The main part of the paper deals with the division of the succession into 8 units with appropriate sub-divisions, and these are discussed in detail, with descriptions of exposure, lithology, fauna, contacts and thicknesses of each unit. These lithological units are listed in Table I. Some consideration is given to the faunal assemblages which they contain and restricted larger fossils are listed in Table II. The conditions of deposition are then considered and the stratigraphic relations are briefly reviewed.

I INTRODUCTION

Detailed stratigraphic investigations in the coastal areas south of Adelaide were carried out by the writer in 1951 in the course of his studies for the Honours Degree of Bachelor of Science in the University of Adelaide. This area had attracted attention of palaeontologists and stratigraphers since it was described by Tate (1878, 1879, 1899; see also papers by Tate and Dennant, Howchin, Chapman and others). The work was based on a plane-table survey. A structural profile section was constructed and the main stratigraphic observations presented in the form of columnar sections. Many fossils, larger as well as microscopic, were collected but not all of them could

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be identified in the time available for this research. Its main objective was the establishment of the sequence of strata, their stratigraphic relations, lithological characters and thicknesses.

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II GENERAL DESCRIPTION

1 Pre-Tertiary Basement

To the north of the sand quarry at Ochre Point there are steeply dipping Pre-cambrian chocolate shales overlain by a greyish-green grit with limonitic bands, a hard grey to reddish quartzite and consolidated to friable sandstones, the latter being somewhat obscured by recent deposits. They have a dip of approximately 50° in a direction 121° (true). From observations made immediately to the north of the sand quarry, it is suggested that the sandstones are probably the source of some, at least, of the quarry sands. These beds, tentatively called Pre-cambrian, are not, however, regarded as directly underlying the white sands. A clayey bed, locally known as pipe-clay, which does not show bedding, is exposed in the pit used as a loading ramp adjacent to the elevator and loading construction, and in a small drain running westerly from the quarry, below the bridge west of the building.

A measurement of the height of the base of the sands was made in a pit east of the elevator and loader, but this pit has since been cemented in. The bed has a purplish stained appearance and shows Liesegang rings. Polished quartz pebbles and cobbles are occasionally found within this bed and small lenses of sandy material may be seen. One such cobble was taken from approximately 7 feet from the top of this bed (sample number A.182 [1]). The unstratified and unsorted nature of this bed, together with the fact that occasional erratics are found, indicates strongly that this is a glacial till. Since it is similar in appearance to the till at Hallett Cove, I have tentatively classed this bed as ?Permian. This bed is 14 feet thick and is underlain by a fine sand at least 12 feet thick. These measurements were made in a well in the quarry to the west of the elevator and loader and are taken from Dr. K. R. Miles' report on the Noarlunga Sand Deposit (1945).

2 Cainozoic Succession

Gently dipping Pre-Pliocene Tertiary sediments overlain unconformably by almost horizontal Pliocene sands and limestones which are capped by approximately flat Pleistocene (?) and recent sediments are to be seen for a greater part of the coastline between the sand quarry and Snapper Point. This succession is described in detail in the following pages.

[1] Samples and grid slides with foraminifera have been deposited in the Palaeontological collection of the University of Adelaide.

3 STRUCTURE

In a section such as this where the dip rarely exceeds 5° and where, in most cases, apparent dips only have been measured, the determination of structure and calculation of the thicknesses of beds present considerable difficulties.

Observations made in the cuttings at the bottom of the sand quarry suggest that the base of the North Maslin Sands has a slight dip towards the north-west. Accurate determination of this dip will be possible should the floor of the quarry be cut below its present level, and the base of the sands reached in other parts of the quarry.

The dip of the base of the overlying brown and green sands is also difficult to determine because the contact between the two formations is evident only in three places. Information from the bore records cannot be used because there is insufficient evidence to indicate where the actual contact occurs and the contact, although it occurs over a probable distance of approximately 20 chains, is masked by overlying Recent deposits. However, the contact has been revealed in the south of the quarry, where it has a dip (true) of 7½°, 201° (true), in a small stream-course immediately south of the quarry, and also at the base of the southern wall of the gully (locally known as the "Canyon") at its westernmost extremity. By calculation of the heights above mean sea level of the contacts at these exposures, approximately 88 feet at the sand quarry, 20 feet at the gully, and due to the fact that the brown sands are exposed down to a height of less than 50 feet on the small limonite-capped hill south of the quarry, it is estimated that the dip of 7½° as seen in the sand quarry quickly flattens to a dip of not more than 2°. This estimation was made along the line of true dip.

The top of the brown sands is irregular and the dip has been calculated on a regional scale by estimation of the height at three points and using the method outlined by Lahee (1931, p.635). The strike is approximately 162° true and the dip approximately 2°. Overlying the brown sands are polyzoal sands and limestone becoming glauconitic towards the top. There are transitional marls above the glauconitic limestone and these are overlain by the banded hard and soft marls which form Blanche Point. The dip of approximately 2° remains constant throughout these beds but there is a gradual change in the strike. The top of the glauconitic limestone strikes approximately 145° whilst the banded marls have a true strike of 139°. Conformably above the banded marls are the soft marls which have, at their upper limits, an apparent dip of 1½° approximately in a direction 195°.

The freshwater red sands and clays exposed in Chinaman's Gully have, at the top, a dip of 2°-3° (200° true). This was measured by Abney Level on a platform which is exposed just north of Aldinga Creek during winter months. Estimation of the dip of the overlying polyzoal beds from here south to where they pass below sea-level is impossible by the use of Lahee's method because the coastline may be regarded as almost straight. The only platform from which dip may be determined in a similar manner to the method used on top of the Chinaman's Gully beds occurs just north of the prominent point approximately ½ mile south of the remaining jetty piles at Port Willunga. The dip here is still 2°-3° but the strike is approximately 063° (true). The reefs which occur in the vicinity of the polyzoal sandy beds confirm the south to south-eastern dip direction.

4 PHYSIOGRAPHY

The coastline from the sand quarry to Snapper Point consists principally of youthful cliffs cut in the sediments already briefly described. More resistant beds, such as the Pre-cambrian quartzite at Ochre Point, the Blanche

Point Banded Marls and the hard sandy limestone at the top of the Pliocene beds, form prominent points whilst less resistant beds have been eroded away to form embayments in the coastline in this section. The hard polyzoal and glauconitic limestones and harder bands in the Blanche Point marls and in the Port Willunga polyzoal beds form reefs, some of which are rich in marine life, from just north of Blanche Point at varying intervals to Snapper Point where the upper hard sandy Pliocene limestone forms an extensive reef. From observations made at low tide from on top of the cliffs at Snapper Point, this latter reef appears to be the crest of a very slight anticline which plunges seaward.

The general succession is interrupted by the mouths of three creeks. The northernmost of these, about 500 yards south of the sand quarry is known locally as the Canyon, due, no doubt, to the fact that the walls of the cutting are almost vertical. The outlet to Bennett's Creek breaks the succession 500 yards south of the Canyon whilst just below Port Willunga, at the northern limits of the township, the Aldinga Creek enters the sea. Whilst water flows from these creeks into the sea after heavy winter rains, the outlets are generally separated from the sea in the drier seasons of the year by sand. There is evidence to suggest that each of these creeks was of larger dimensions in Post-Pleistocene times. Small streams traverse the section at Maslin Beach and between Blanche Point and Port Willunga. The cuttings formed by such streams are not generally important but in Chinaman's Gully and two cuttings immediately north of it, good exposures of the second non-marine formation are revealed.

Above the cliffs, the coastal section area is relatively flat, undulating only where traversed by creeks. A thin layer of kunkar underlying Recent soils and deposits is almost continuous throughout this area, and, apart from the undulations, it has a regional dip of only 1 in 200 feet from the sand quarry to Snapper Point. Generally the basal parts of the section may be regarded as wave-cut cliffs. However, the effects of other erosive agents may be seen in the upper parts of the section and where the basal parts of the section are composed of sands. Just south of the sand quarry the basal beds are composed of the brown sands and, although limonitic bands provide a certain amount of protection against erosion, small hilly slopes with moderately steep inclination have been formed between streams; such hillocks are capped with limonite. Between the Canyon and Bennett's Creek, these sands receive a certain amount of protection from the capping of Pliocene limestone but from Bennett's Creek to the trig. point, this capping does not exist and the erosional effects of the small streams and their tributaries beginning in the overlying ?Pleistocene clays have produced rounded valleys with steep sides between protruding spurs. These valleys resemble hanging valleys elevated above beach level by the rapid erosion of the lower beds by wave action. From the trig. point to almost the southern limits of Maslin Bay and from Blanche Point to Chinaman's Gully, platforms have been formed above the hard upper layer of Pliocene limestone. The overlying ?Pleistocene clays are being eroded away and form a series of rounded protuberances with steep sides between stream courses. The erosion of the ?Pleistocene clays is occurring in a similar manner along the length of Blanche Point and from Chinaman's Gully to Snapper Point. Along these portions of the section the lower beds are more resistant to the effects of waves and consequently, over a long period, they have become the protruding points mentioned at the beginning of this discussion. They thus become exposed to the full effects of wave action with the resultant production of almost vertical cliffs which are continuously being eroded away. It is because of this that such platforms as have been formed above

the hard upper Pliocene limestone in those parts of the coastline described earlier as embayments, have not had the opportunity of being formed in these portions. The steep nature of most of the ?Pleistocene clay deposits is due to the thin protective layer of kunkar which underlies the Recent soils.

Sand dunes and banks occur at various intervals along the base of the section during the summer months and obscure certain beds in the succession. However, where such deposits are purely aeolian and not covered by vegetation, they will be removed together with a greater part of the beach sand by the high seas generally occurring during winter months. Sand hills and recent deposits covered with vegetation are present in the northern parts of Maslin Bay and to some extent between Blanche Point and Port Willunga.

Land-slides have occurred throughout the section with the result that, in some places, lower beds in the section have become obscured by ?Pleistocene clays, whilst in other places cliff faces have collapsed and produced the same effect. The fallen blocks, which occur amongst the scree at the base of such collapsed faces, have been used for the correlation and sampling of such beds in the section to which they can be proved identical, where such beds are inaccessible. A certain amount of obscurity as to the nature of beds in cliff faces has occurred as a result of surface weathering.

A small shallow cave exists near the south-eastern corner of Maslin Bay where sands underlying the polyzoal limestone have been eroded away. A deep cave has been tunnelled through the polyzoal and glauconitic limestones and overlying softer transitional marls along the northern side of Blanche Point, and further west above a reef formed by the limestones the soft, transitional marls have been eroded away, leaving a large shallow cutting beneath the overlying banded marls. The only other caves occurring in the section have been tunnelled in the polyzoal beds below Port Willunga by fishermen.

Fresh to saline water has been observed emerging from above the glauconitic limestone reef in the large shallow cutting immediately north of Blanche Point and from the polyzoal beds in the vicinity of the first reef, locally known as "Spring Reef," south of the old Port Willunga jetty.

To the north-west of Blanche Point is a remnant of a former extension of the banded marls, which is known as Gull Rock.

A Low Water Mean Line is included on the map to indicate those portions of the coastline which are generally inaccessible due to the sea. At times of lower than Mean Low Water tides, however, the reef just north of Blanche Point is exposed above sea level and it is possible to examine beds almost to Blanche Point.

There are two series of minor faults, one just below Port Willunga township, the other approximately a quarter of a mile south of the piles of the former jetty. The greatest of these faults has a throw of only 9 feet, this being the displacement on the southern side of the downfaulted block (graben) below Port Willunga. The faulting occurred in Pre-Pliocene times although there is evidence to suggest that in the southernmost series there was a slight displacement in Pliocene or Post-Pliocene times. This is indicated in a slight downthrow of the Pliocene beds between the two greater of the series of minor faults. All faults dip steeply to either the east or the west and the strike, as measured by prismatic compass, is north-south in the case of the larger, more prominent faults. Whilst there is no evidence of a continuance of these faults at Blanche Point, prominent fracture lines extend here in a more or less north-south direction, i.e., in the general direction of the minor faulting.

III. STRATIGRAPHIC OBSERVATIONS

Under this heading it is intended to subdivide the succession into a number of lithological units and to name the pre-Pliocene Formations (but not their subordinate Members) according to the Australian Code of Stratigraphic Nomenclature (Raggatt, 1950). After the completion of his thesis the writer was informed of Miss I. Crespin's intention to publish stratigraphic names for the succession here described. The name "Maslin Sandstone" will be given by Miss Crespin to the combined North Maslin and South Maslin Sands of this paper. The Pliocene strata will be formally named by Miss Crespin. New names are here proposed for the pre-Pliocene Formations as these are smaller and more detailed that the more comprehensive divisions recognised by Miss Crespin. No attempt has been made to give a time and time-rock classification to the majority of these units because time has not permitted a full enquiry into the ranges of index fossils. (See Table I and Fig. 1.)

Formation 1: North Maslin Sands (First Non-Marine Formation)

Exposure—From the Noarlunga Sand Quarries Ltd. quarry situated approximately 50 chains south east of Ochre Point to the base of the southern wall of the Canyon at its western limits. Dr. Miles (1945) mentions an exposure "at the mouth of a gully, just above the beach level" immediately south of the quarry, but this was not observed. However, the sands at their upper contact are exposed in the stream course just below the road leading into the quarry.

Lithology—Cross-bedded sands varying in grain-size from pebbles to very fine sands with the coarsest particles at the base of individual beds. Fine silty clay bands and yellow clay lenses occur at a height of approximately 10 feet from the base; the former have a laminated appearance and are somewhat flexible; the latter are sometimes nodular, and such clays occasionally yield fossilized plant remains. These are best seen in the northern parts of the quarry. According to Miles (1945): "The sand throughout the deposit is substantially free from organic material, and, for the most part, is sufficiently fine and free from clay substance to be used as ordinary building and concrete material without screening." The sands are predominantly white but variously coloured bands and lenses occur more pronouncedly in the upper beds.

Flora—Chapman (1935) described some plant remains sent to him by Sir Douglas Mawson. Such remains are not as abundant as Chapman suggests in the "pipe-clay" which occurs towards the base of the sands. ("Pipe-clay" has been used in quotation marks because it is most probable that this is the clay occurring at an approximate height of 10 feet from the base of this formation and not the basement rock, which is known locally as pipe-clay.) Clays with fossilised plant remains have been seen east of the elevator in the gully which leads towards the "Flying Fox." These should not be confused with the silty bed which contains lignitic material occurring at the top of the Pliocene sands.

Contacts—The base of this formation is marked by a band of smooth polished quartz pebbles lying unconformably above the ?Permian till and is exposed in cuttings adjacent to and west of the loader and elevator. As exposed in the southern parts of the quarry just below the base of the Pliocene sands, a transition occurs between the upper parts of the North Maslin Sands and the overlying limonitic quartz sands which are green at the base.

TABLE I

UNIT No.		FORMATION	MEMBER	LITHOLOGY	THICKNESS (Feet)
8		? Pleistocene and Recent Deposits		Mottled red and green clays and sands and Recent deposits	59 maximum
		FORMATION	MEMBER		
7		Pliocene Limestones		Limestones and sands with some clays	18–20
			Angular Unconformity		
6		Port Willunga Beds		Sandy, polyzoal and clayey cross-bedded sediments varying in composition and colour	111½
5		Chinaman's Gully Beds		Gravels to silts with red, yellow, brown banded clayey beds — 2nd Non-Marine Beds	5½ maximum
	C		Soft Marls	Soft marls with one hard band and hard nodules	57
4	B	Blanche Point Marls	Banded Marls	Alternate hard and soft bands, some of the former being siliceous	37
	A		Transitional Marls	Limey glaueonitic marls to marls	7½ maximum
	B		Glauconitic Limestone	Richly fossiliferous green glauconitic limestone	3 maximum
3		Tortachilla Limestones			
	A		Polyzoal Limestone	Richly fossiliferous polyzoal sands and limestone	3–6
2		South Maslin Sands		Mainly brown limonitic quartz sands, green and purple in part	100–160 average
1		North Maslin Sands		White gravels and sands with some clay lenses — 1st Non-Marine Beds	64 approximate
				Total :	388½–451½

Thickness—As already mentioned under the discussion of Structure, the true dip of the base of these beds is not determinable and true thickness cannot be measured. The height of the base as measured in a temporary cutting east of the elevator and loader during the plane table survey is 26 feet. Since the height of the base of the Pliocene would be approximately 90 feet (by estimation from measurements made to the south) in this vicinity, the thickness of this formation is given as approximately 64 feet.

Remarks—Chapman's suggestion of Lower Oligocene age for this Formation is in conflict with later foraminiferal evidence which indicates Upper Eocene age of the Tortachilla Limestones.

FORMATION 2: SOUTH MASLIN SANDS

Exposure: This formation extends from the southern parts of the sand quarry to the small shallow cave in the south-east corner of Maslin Bay, a distance of almost 1¼ miles.

Lithology—The sands consist predominantly of well-rounded grains of quartz and limonite loosely consolidated with a calcareous cement. The minerals occur in approximately equal amounts in the sands but there are other constituents including small green clay pellets, pebbles of quartzite, etc., which occur in small amounts. Whilst these beds vary from a gravel to a fine sand, they are predominantly coarse to very coarse sand. The color varies from mainly brown, due to the limonite, to green and light-purple which colors apparently arise from staining of the calcareous cement. Cross-bedding occurs throughout the formation and pebble bands frequently form the base to successive beds. Thin laminae of limonite, often rich in quartz grains, form a capping to successive beds in the lower parts of the formation, and these, together with the pebble bands, emphasise the cross-bedding. Such limonite bands, as mentioned under Physiography, form a capping to the small hilly slopes south of the sand quarry. There is a brown earthy bed one foot thick which contains quartz pebbles, 3 feet above the base of the formation. This is probably a bed of fresh-water origin occurring in the transition from terrestrial to marine environment.

Glauconite, as such, has not been observed in the sands, but it is believed in view of the similarity in properties of some of the limonite grains to those of glauconite, that this mineral may have been originally deposited or formed. A sample of the "green-sand" overlying the "pipe-clay" and sands in the Maslin Bay quarry was also sent by Sir Douglas Mawson to Chapman (1935) who ascribed the shape of many "glauconitic" casts to the infilling of foraminiferal tests, "whilst others are replacements of ovoid pellets variously ascribed to the excreta of worms, echinoderms or fishes." He also suggests that "these pellets are similar to those found in the glauconites and marls of Upper Oligocene age in the borings at Lakes Entrance, Gippsland." Edwards (1945), in a discussion on the Glauconitic Sandstone of the Tertiary of East Gippsland, Victoria, describes, with illustrations, the formation of glauconite from biotite and mentions three facts:

(1) Faint traces of biotite cleavage are retained by glauconite,
(2) glauconite can develop a mammillated outline, and
(3) "As the gelatinous glauconite dried, it shrank, developing rounded edges and shrinkage cracks."

Further, the same author points out ". . . . glauconite is an unstable mineral which readily alters to limonite or ferruginous clay if exposed to oxidising conditions, so that this a normal change for glauconite to undergo." Some limonite grains exhibit the latter two, of the three properties outlined above, and since the change from glauconite to limonite under oxidising

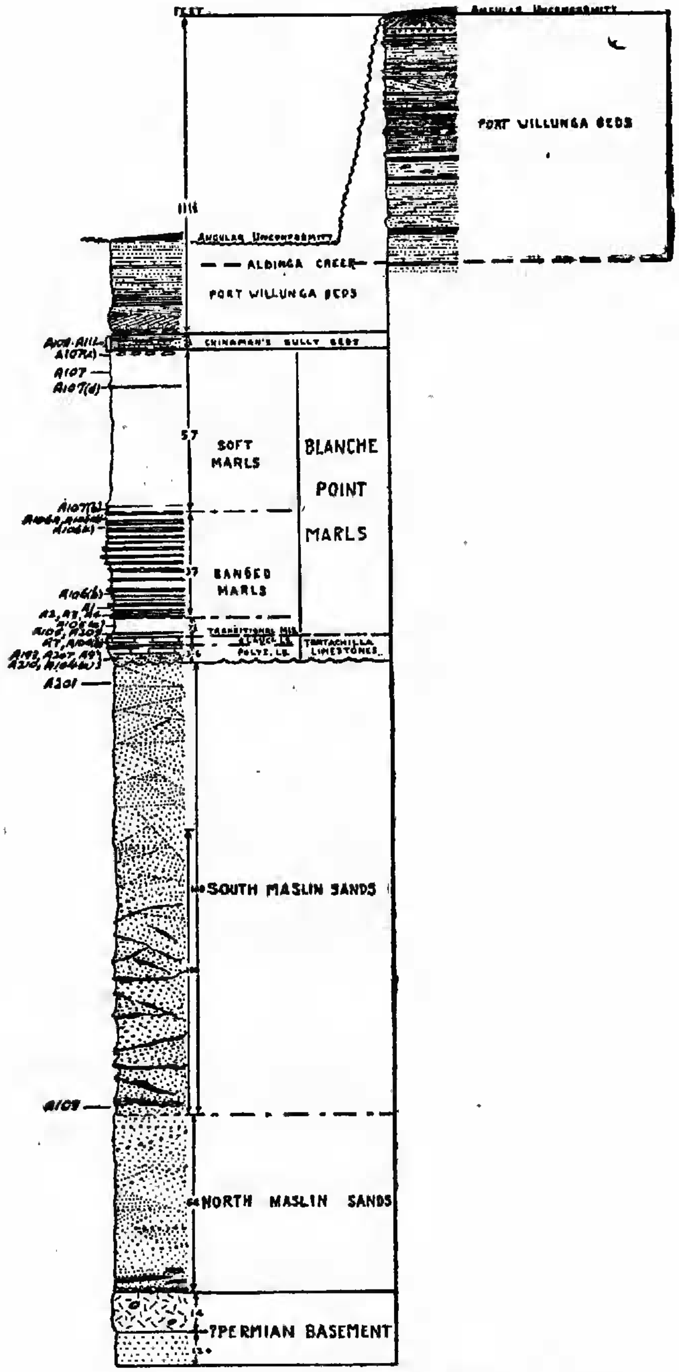


FIG. 1. COLUMN OF PRE-PLIOCENE BEDS.

conditions is a normal one, the above statement that glauconite may originally have been deposited or formed is substantiated. It is not known whether such alteration occurred during or after deposition.

Fauna—Fossil remains, although by no means plentiful, occur throughout the formation. Washings of samples from various horizons have revealed

the presence of foraminifera, echinoid spines, sponge spicules and polyzoa. Sample A103 from the basal beds yielded *Gyroidina?* and others (undet.), whilst casts of Polymorphinidae, similar to those found in the polyzoal sands immediately above this formation, are common in the uppermost beds (Sample A201) exposed just above "Uncle Tom's Cabin" towards the south of Maslin Bay. Lamellibranchs, generally fragmentary, have been noted from various horizons, one occurring at beach level between the trig. point and the first boat shed to the south. *Lima bassii* (T. Woods) var.b. (Tate) and *Barbatia* sp. (samples A188, A208 respectively) have been identified. Small gastropods have also been collected.

Contacts—In the southern parts of the sand quarry, there is a sharp transition from the underlying North Maslin Sands to a green sand bed with white nodules which bed constitutes the base of the South Maslin sands. The upper beds are overlain unconformably by a polyzoal limestone which is brown and unconsolidated at its base in places. The junction of this unconformity with the angular unconformity at the base of Pliocene beds is not exposed but is thought to exist on the southern side of the spur immediately below the trig. point. The upper contact, however, may be seen from just south of this spur to the south-east corner of Maslin Bay.

Average Thickness—By calculation, 100-160 feet.

(Note: The methods of determination of thicknesses are given in detail in the original thesis, copies of which have been deposited in the Barr Smith Library, University of Adelaide.)

Remarks—Howchin (1923) regarded this formation as a freshwater series, but rare remains of marine fossils have been found throughout the formation, which is now regarded as dominantly marine.

Formation 3: Tortachilla Limestones

Member 3A: Polyzoal Limestone

Exposure—From just south of the spur below the trig. point to the north side of Blanche Point where it is exposed from the beach to the small cave about 100 yards east of Blanche Point. The upper parts of the bed are exposed at low tides as an almost flat reef which extends from just west of the cave to just east of Blanche Point. This member is not exposed south of Blanche Point.

Lithology—From the base upwards this member consists of unconsolidated polyzoal sands rich in limonite grains grading into a hard, richly fossiliferous polyzoal limestone which becomes partly glauconitic towards the top. The limonite grains are less abundant in the upper parts and hence the color also grades from the base upwards from predominantly brown to pinkish-white. In thin section quartz grains are seen to be present to almost the same extent as the limonite grains in the upper consolidated limestone. Sections of microfossils are plentiful and occur with the above-mentioned minerals in a richly calcareous matrix.

Fauna—

Casts of different species of Polymorphinidae similar to those occurring towards the top of the underlying sands; and others (A210, A9) — *Terebratulina* sp., *Terebratulina lenticularis* Tate, *Magadina* sp., *Magellania tateana* (Tenison-Woods), *Ostrea* sp., *Aturia clarkei attenuata* Teichert and Cotton was obtained from approximately 3 feet above the base of this formation just above "Uncle Tom's Cabin" by Dr. M. F. Glaessner and identified by him. *Pseudechinus woodsii* (Laube), *Fibularia gregata* Tate, *Australanthus longianus* (Gregory),

Echinolampas posterocrassus (Gregory), *Eupatagus* sp. (*a*) are common. Other fossils include an alcyonarian coral, a comatulid crinoid, crinoid stems, many species of polyzoa, sponge spicules, gastropod casts, ostracodes and shark's teeth.

These fossils occur in my samples Nos. A104(a), A193, A207, A210 and Nos. A7 and A9 (collected by Dr. Glaessner).

Contacts—The formation is unconformably underlain by the South Maslin Sands. The change from Polyzoal upward to Glauconitic Limestone is transitional and the two units are regarded as Members of a Formation.

Thickness—The maximum thickness of 6 feet is to be seen in the south-east corner of Maslin Bay where the basal polyzoal limonitic sands show their greatest development in a trough of the unconformity which is somewhat sinuous. These sands vary in thickness from 3 inches to 3 feet whilst the consolidated limestone above generally has a thickness of 3 feet, hence the thickness of the Member is given as 3 to 6 feet.

Member 3B: Blanche Point Glauconitic Limestone

Exposure — This member is exposed over almost the same distance in Maslin Bay as the underlying Polyzoal Limestone. It may be seen from about 250 yards south of the Trig. Point almost to Blanche Point where the lower parts form the top of the reef already mentioned under 3A. Just east of the small deep cave 100 yards east of Blanche Point along the northern side, this member forms the top of a small platform.

Lithology—This is in general a hard calcareous rock rich in glauconite, hence the predominant green color. It is very fossiliferous and there are some small pockets of softer glauconitic material similar to those occurring in the upper parts of the underlying polyzoal limestone. There are some grains and pebbles of limonite and quartz in this rock also, and in some cases fossil tests which have not become infilled with glauconitic clay show a secondary formation of calcite in clear crystalline form.

Fauna—

FORAMINIFERA: *Uvigerina, Angulogerina, Anomalina, Astrononion, Pullenia, Siphonina, Gyroidina, Nonion, Discorbis, Eponides, Bulimina, Gümbelina, Bolivina, Bolivinita* and others. (A7).

POLYZOA: *Reticulipora transennata, Lichenopora* sp.

CORALS: Tate (1878) lists *Amphihelia zic-zac* (Tenison-Woods) as occurring in the Glauconitic Limestone north of Blanche Point.

BRACHIOPODA: *Terebratulina lenticularis* Tate, *Magellania tateana* (Tenison-Woods), *Victorithyris pectoralis* (Tate), *Victorithyris sufflata* (Tate), *Liothyrella tateana* (Tenison-Woods), *Aldingia furculifera* (Tate), etc.

LAMELLIBRANCHIA: *Notostrea tatei* (Suter), *Spondylus* sp., *Chlamys* sp., *Chlamys flindersi* (Tate), *Glycimeris* sp.

ECHINOIDEA: *Stereocidaris australiae* (Duncan), *Pseudechinus woodsii* (Laube), *Fibularia gregata* Tate, *Australanthus longianus* (Gregory), *Eupatagus* sp. (a).

Other fossils include worm tubes and lamellibranch shells and casts, gastropod casts, crinoid remains, echinoid spines and ostracodes.

Contacts—The transition from the underlying polyzoal limestone to this bed has already been discussed. Marls which are highly glauconitic at the base overlie the Glauconitic Limestone and there is once again some evidence of a transition between these two formations. Due to erosive agents, since the overlying marls are very much softer, the limestone protrudes from below them and the contact is generally well shown.

Thickness—3 feet (maximum).

Formation 4: Blanche Point Marls

Member 4A: Blanche Point Transitional Marls

Exposure—From about 150 yards north of "Uncle Tom's Cabin" along Maslin Beach in the south-east corner of the bay to the north side of Blanche Point. Whilst this member reaches almost to Blanche Point along the northern side, it is no longer exposed south of the Point. It has been eroded away above the reef just north and east of Blanche Point to form a large shallow cutting beneath the overlying banded marls (Member 4B).

Lithology—This is essentially a marly bed, dark grey at the base due to the numerous glauconitic grains, becoming lighter in color higher up, although still retaining a speckled appearance. An analysis of a sample from the middle parts of this formation revealed that the bed here contains 80% $CaCO_3$ with some insolubles, including quartz, Fe_2O_3 and clay. On petrological considerations, the sample would be classed as a limey marl, but this is not entirely satisfactory because this formation is rich throughout in microfossils which have calcareous tests. As mentioned above, the composition varies from the base which is comparatively rich in macrofossils and predominantly glauconitic to the upper richly calcareous parts, but it is considered that the formation may be called a marl.

Fauna—The fauna includes the foraminifera *Uvigerina, Angulogerina, Anomalina, Astrononion, Nonion, Gyroidina, Discorbis, Pullenia, Siphonina, Notorotalia, Bulimina, Gümbelina, Bolivina, Bolivinopsis, Bolivinita,* and others (A105, A105a, A209).

It is from the base of this formation that *Hantkenina alabamensis* Cushman was taken by Parr.

Brachiopoda: *Victorithyris pectoralis* (Tate), ?*V. sufflata* (Tate), *Terebratella* (?) *pentagonalis* (Tate), *Aldingia* sp. and others.

Lamellibranchia: *Notostrea tatei* (Suter), *Notostrea lubra* Finlay.

Other Fossils include a small Gastropod, Polyzoa, sponge spicules and Ostracodes.

Contacts—The glauconite-rich basal beds and the fact that macrofossils similar to those in the underlying bed occur also towards the base supply evidence of a transition between the underlying Glauconitic Limestone and this Marl. This contact reaches the base of the Pliocene as is to be seen in a small stream-course about 150 yards north of "Uncle Tom's Cabin." Overlying this Transitional Marl Member is the first hard band of the Blanche Point Banded Marls.

Thickness—The maximum thickness, by measurement, is 7½ feet.

Remarks—In view of Parr's discovery of *Hantkenina* the basal part of this formation must be assigned to the Upper Eocene.

Sample A105 was taken from the base and A105 (a) from 4 feet above the base in the vicinity of a fence which follows down over ?Pleistocene and Pliocene beds along the eastern limits of Maslin Bay, i.e., approximately 250 feet south of "Uncle Tom's Cabin." Sample A209 was collected from the base of the formation just west of the small shallow cave in the south-east corner of Maslin Bay.

Member 4B: Blanche Point Banded Marls

Exposure—From between "Uncle Tom's Cabin" and the fence just mentioned, where the base of the first hard band meets the base of the Pliocene, to just south of Blanche Point where the upper of the series of hard bands passes below sea-level. At this latter position the steep nature of the cliff-

faces common throughout almost the entire distance of exposure of this formation along the coastline is lost and from here south to Chinaman's Gully, a change in the nature of the coastline is noted.

Lithology—

(5) Top: Soft clayey marls similar to the overlying Member 4C with hard grey nodular bands three inches thick at heights of ¾, 3, 3¾ and 5¼ feet above the base. The dip of the banded marls was determined by Lahee's method (1931) using the top of the band at 3⅞ feet - - - - - -	5½ feet
(4) Grey marls with three hard bands at heights of 2, 4 and 5½ feet above the base. Intervening softer bands are similar to the hard bands in composition but are not as consolidated -	6 feet
(3) Soft yellow-grey marls with four hard grey nodular bands and capped by a 1-foot thick band of hard grey marl. Besides *Turritella aldingae* Tate which is abundant throughout the formation, these beds are rich in Polyzoa - - -	8 feet
(2) Rubbly marls generally light grey in colour with irregular hard and some thin and nodular grey bands - - - -	12 feet
(1) Greenish-grey and light grey marls, alike in appearance to the underlying Transitional Marls with a hard grey nodular band 2 feet up from the base and a hard light grey band 1 foot thick at the base - - - - - - -	5½ feet
Total thickness -	37 feet

A chemical analysis revealed that the $CaCO_3$ content is 40% in the hard marls in bed (4). The examination of insoluble residues revealed a large percentage of silica. This was expected since microscopic examination of similar beds had shown relatively large numbers of sponge spicules. A thin section of Sample No. A1 revealed a green mineral (?glauconite) as occasional grains and forming a part of the matrix. Fissures developed in these beds have a north-south trend and may be lines of weakness culminating in the minor faulting seen almost due south in the Port Willunga Beds.

Fauna—

FORAMINIFERA are common but have not yet been fully studied.

BRACHIOPODA occur in sample A3.

CORALS: *Flabellum distinctum* Edwards and Haime. Tate (1878) also records *Amphihelia striata* Tenison-Woods from limestone bands in clays at Blanche Point.

LAMELLIBRANCHIA: ? *Notostrea tatei* (Suter), *Spondylus* sp., *Notostrea lubra* Finlay (not *in situ* but believed to be from the basal beds), *Propeamussium atkinsoni* (Johnston), *Chione multilamellata* Tate. Tate records from "Turritella Limestone bands Blanche Point": *Spondylus gaederopoides* McCoy, *Limopsis multiradiata* Tate, *Barbatia dissimilis* Tate.

GASTROPODA: *Tenagodes adelaidensis* (?), *Lyria* (?) sp., *Turritella aldingae* Tate, *Vermicularia* sp., *Siliquaria* sp., *Trivia avellanoides* McCoy.
Tate records from "Turritella bands, Blanche Point": *Epitonium lampra* (Tate).

SCAPHOPODA: *Dentalium* sp.

CEPHALOPODA: *Nautilus* sp.

OTHER FOSSILS include crinoid stems, sponge spicules, echinoid spines and octracodes. Sponge spicules are notably plentiful in the uppermost parts of this formation. An otolith was collected from bed (5), Sample A106 (d).

and other fish remains include shark's teeth and fish vertebrae. Large worm burrows have been noted in harder bands lower in the formation.

Additional fossils described by Tate and others are found in works listed in Singleton's comprehensive paper of 1941.

Contacts—The formation is underlain by the Blanche Point Transitional Marls and overlain conformably by the Blanche Point Soft Marls, Member 4C. The upper contact joins the base of the Pliocene almost directly above the small shallow cave in the south-east corner of Maslin Bay.

Thickness—37 feet.

Member 4C: Blanche Point Soft Marls

Exposure—The base of this formation meets the base of the Pliocene above and approximately 100 feet west of the small shallow cave in the south-east corner of Maslin Bay. The top of the formation meets the Pliocene approximately 400 yards north of Chinaman's Gully and this may be seen in a stream-course exposure. The top of the Marls is last observed just to the north of Aldinga Creek where it is decidedly blackish in color and passes down below sea-level. This however is only to be seen when there is little or no sand cover.

Lithology—This is essentially a brownish to greenish-grey marl, generally soft and clayey (more so towards the base), with some hard grey nodules dispersed irregularly throughout. There is a hard grey-black band which forms a reef due west of Chinaman's Gully at a height of approximately 45 feet and a thin nodular band 1¼ feet from the base. The uppermost bed is a dark greenish-grey colour and fossiliferous, being rich in *Limopsis chapmani* Singleton and *Turritella aldingae* Tate, the latter, however, being common throughout the formation.

A sample from the topmost *Limopsis* bed, A107 (c), was examined for foraminifera which were found to be very small and not numerous. The bed is extremely rich in glauconite which occurs as green pellets. Another characteristic feature of the upper beds of this formation are the white marly nodules which are sometimes of quite large dimensions. They appear to be non-fossiliferous and may possibly represent the relics of an erosional surface which existed prior to the deposition of the overlying non-marine sediments. The Blanche Point Marls are generally grey in colour throughout, some horizons being darker than others and this may be due partly to the presence of organic matter.

Analysis of Sample No. A107 revealed 47·5% $CaCO_3$, together with clay and some silica which were left as insolubles.

Fauna—

FORAMINIFERA: *Bulimina, Gümbelina, Bolivina, Uvigerina, Angulogerina, Anomalina, Astrononion, Gyroidina, Discorbis, Pullenia, Sphaeroidina* and others.

BRACHIOPODA: *Victorithyris sufflata* (Tate) and others.

LAMELLIBRANCHIA: *Limopsis chapmani* Singleton, *Dimya sigillata, Lentipecten* sp., *Lentipecten* cf. *victoriensis* Crespin, *Propeamussium atkinsoni* (Johnston), *Anomia* cf. *cymbula* Tate, *Cardium* sp., *Chione cainozoica* Tenison-Woods, *Arca equidens* Tate, *Chione multilamellata* Tate, and others.

GASTROPODA: *Turritella* sp., *Turritella aldingae* Tate, *"Murex"* sp., *Ancilla ligata* Tate, *Natica* sp., *Voluta pagodoides* Tate, *Trivia avellanoides* McCoy and *Vermicularia* sp.

SCAPHOPODA: *Dentalium* sp.

OTHER FOSSILS include sponge spicules and ostracodes.

Thickness—57 feet.

Contacts—The base of the formation is underlain by the topmost hard band of the alternate hard and soft bands of marl which form Member 4 B, whilst immediately above are the basal beds of the second non-marine beds, *i.e.,* laminated green, brown and yellow clays with white nodules.

Formation 5: Chinaman's Gully Beds
(Second Non-Marine Formation)

Exposure—These beds meet the base of the Pliocene north of Chinaman's Gully, the base at a distance of 370 yards, the top at approximately 290 yards, but except where exposed in stream courses, they are generally obscured by Recent deposits in this vicinity. The best exposure is in Chinaman's Gully, whilst they are also well shown in two small stream cuttings just to the north. They are generally to be seen in part from Chinaman's Gully to Aldinga Creek but not south of the latter locality.

Lithology—Because these beds are easily measured and have some variation in composition they have been listed hereunder in tabulated form with sample numbers and thicknesses.

Lithology	Sample No.	Thickness
Top		
Yellow to brown becoming red laminated clayey to gritty bed, limonitic in part and containing nodules of blue-grey and green sandy clays which show Liesegang rings—this bed is in parts cross-bedded - - - - - - - - - -	A111	11"
Blue-grey silt with parallel bands of coarser sands	A110	8"
Red laminated sandy to clayey bed Thin band of bluish-grey silt Yellow laminated sandy bed Greenish-yellow silt band	A110	1'8"
Interbedded coarse and very fine to medium sands varying in colour from greenish-yellow to white and blue-grey with a hard white sandstone leaf at the base and some white sandy nodules just above the base. - - - - - - - - - -	A109	1'1"
Laminated green, brown and yellow clays with white sandy nodules.	A108	1'0"
Base - - - - - - - - - -		5'4"

In samples of the coarser constituents examined, quartz was seen to be the predominant mineral but there were other dark grains and some muscovite. Clay, sometimes with iron oxides, and silt form the very fine constituents of these beds.

Fauna—Some foraminiferal tests were obtained from sample No. A109, but these are thought to have been derived from the underlying soft marls as remanié fossils during erosion under a terrestrial environment.

Contacts—This bed overlies the Blanche Point Soft Marls and, at the base, shows a marked contrast to the highly fossiliferous grey marls which have fairly abundant white nodules at the upper limits. A green bed with a maximum thick-

ness of 1½ feet overlies the formation, and whilst the break as shown by the change in colour is quite evident, the microfossil assemblage, as discussed under Formation 6, indicates a distinct change in the environment.

Thickness—By measurement, 5½ feet maximum.

FORMATION 6: PORT WILLUNGA BEDS

Exposure—The northernmost limit of this formation is somewhat obscured by Recent terrestrial and aeolian deposits. The top of the lowest member of the formation meets the Pliocene basal unconformity approximately 270 yards north of Chinaman's Gully. This is exposed in the bed of a small stream-course and by estimation, taking into consideration the apparent dip of the beds (approximately 1½° or 120 feet/mile 200° true) and of the unconformity (approximately 0° in the vicinity) the northernmost limit is 280 to 290 yards north of Chinaman's Gully. The southernmost limit occurs where the base of the Pliocene dips below the sand at an approximate distance of 1,000 yards south of the remaining jetty piles at Port Willunga. This distance is based on the level of the beach sand during February, 1951, and will be subject to variation.

Lithology—Due to the variable nature of the members of the formation, a column had to be drawn (Fig. 2), showing such variation, sample horizons and thicknesses. The minor faulting discussed earlier, the thinning of certain beds, cross-bedding and the effects of a relatively deeper Aldinga Creek in post-Pleistocene times have all created some difficulties in the correlation of beds and measurements of thickness. The formation as a lithological unit could be classed as an arenaceous polyzoal limestone with argillaceous bands.

Fauna—

FORAMINIFERA: Sample No. A112, a distinctive assemblage of arenaceous types which have not been identified.

A113: *Anomalina, Sherbornina, Sphaeroidina* and others.

A114: *Verneuilina* (?), *Gumbelina, Bolivina, Uvigerina, Angulogerina, Astrononion, Gyroidina, Nonion, Discorbis, Planorbulina, Sherbornina, Sphaeroidina* and others.

CORALS: *Graphularia senescens* Tate.

POLYZOA: *Cellepora* cf. *verruculata*.

BRACHIOPODA: *Magellania garibaldiana* (Davidson); *Stethothyris* (?) *insolita* (Tate), ? *Magellania tateana* (Tenison-Woods), *Victorithyris sufflata* (Tate), and others.

LAMELLIBRANCHIA: "*Pecten*" cf. *consobrinus* Tate, "*P.*" *eyrei* Tate, *Ostrea arenicola* Tate, *Chlamys asperrimus asperrimus* (Lamarck), *Pinna* sp. *Dimya dissimilis* Tate.

GASTROPODA: *Vermicularia* sp., *Turritella* sp., ? *Mitra* sp., *Cirsotrema mariae* (Tate).

ECHINOIDEA: *Duncaniaster australiae* (Duncan), *Nucleolites* sp., *Linthia compressa* (Duncan), *Pseudechinus woodsii* (*Laube*), *Eupatagus* sp., *Stereocidaris australiae* (Duncan), *Prionocidaris scoparia* Chapman and Cudmore, *Scutellina patella* Tate, *Fibularia gregata* Tate, *Goniocidaris prunispinosa* Chapman and Cudmore.

ASTEROIDEA: *Pentagonaster* sp.

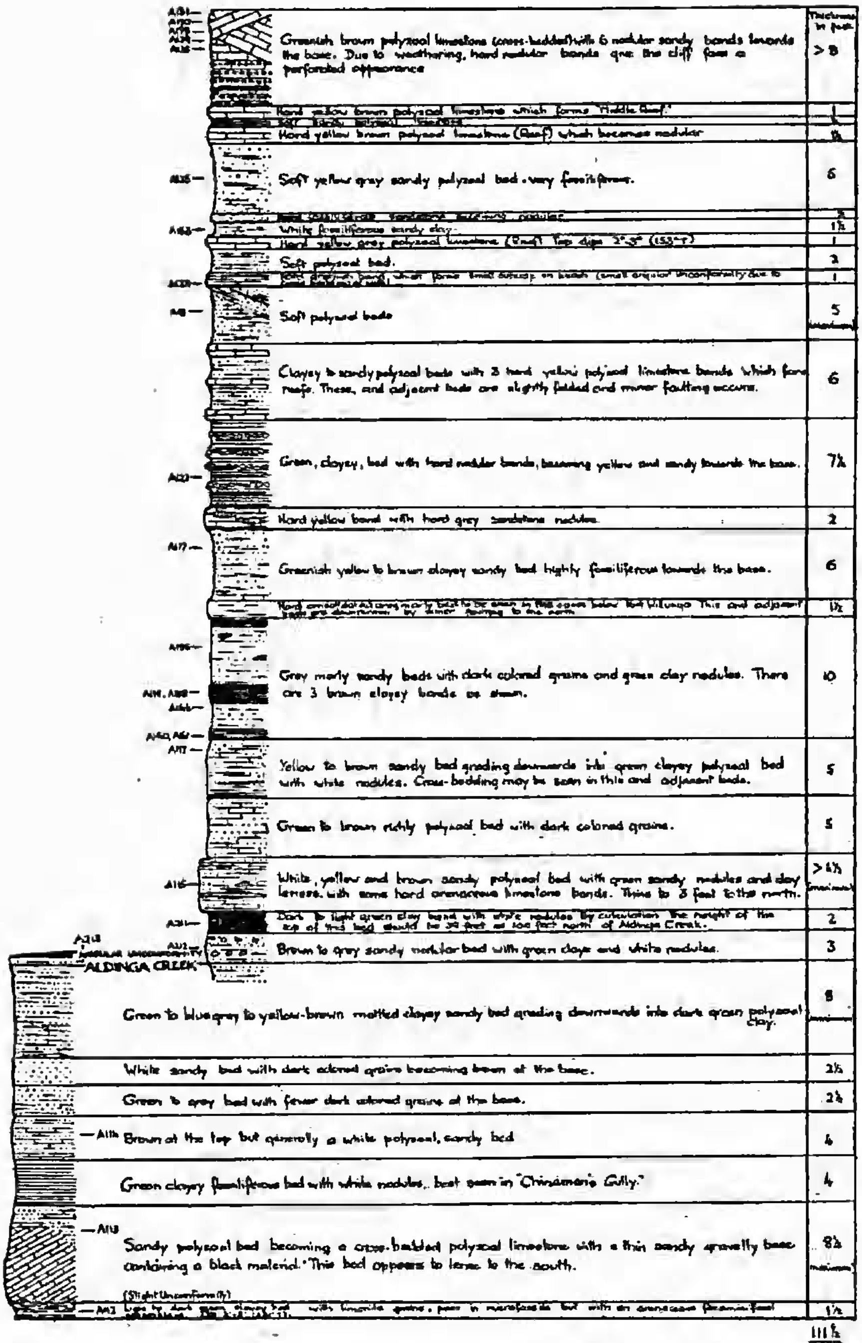
CRUSTACEA: abundant Cirripedia.

PISCES: Tooth of *Odontaspis contortidens* Agassiz, teeth of *Odontaspis attenuata* Davis.

OTHER FOSSILS include worm tubes (A151), and microfossil samples contain Polyzoa, Ostracodes, sponge spicules, echinoid spines, crinoid stem remains.

Hereunder are some additional fossils mentioned by Tate in various publications:

FIG. 2 THE PORT WILLUNGA BEDS.



BRACHIOPODA: *Magellania furcata* (Tate)—"rather rare in the Polyzoal calciferous sands forming the lower part of the seacliffs immediately south of Port Willunga Jetty"; *Victorithyris sufflata* (Tate)—same locality; *Magasella woodsiana* Tate—"yellow calciferous sands, Aldinga Bay."

LAMELLIBRANCHIA: *"Pecten" peroni* Tate "polyzoal limestone, Aldinga Bay."

ECHINOIDEA: *Eupatagus decipiens* Tate—"calciferous sandstone, south side Port Willunga Jetty," *Lovenia forbesi* Tenison-Woods—"calciferous sandstone, Eocene, Aldinga." Tate and Dennant (1896) list also *Maretia anomola* Duncan and the Crinoid *Antedon* sp., from "calciferous sand rock with hard concreted portons at top and siliceous bands at bottom," Port Willunga Jetty, Lower Beds. The reader is also referred to a paper by Miss Crespin (1946) for a list of microfossils, mainly Foraminifera and Polyzoa, which come from her Samples Nos. 1 to 4.

Contacts—The formation is underlain by the second non-marine formation as described under Formation 5. The top of the Port Willunga Beds is not revealed in this succession.

Thickness—by measure 111½ feet.

FORMATION 7: PLIOCENE LIMESTONES

Exposure—Sands and limestones with sands all regarded as Pliocene in age extend continuously from north of Ochre Point to south of Snapper Point.

Lithology—This formation consists predominantly of white and yellow sands and arenaceous limestones with occasional lenses of clayey sands. For the purpose of this discussion, the Pliocene formation will be considered in three divisions numbered 1 to 3.

1. From the north of this succession to 120 yards south of the spur below the trig. point, the formation consists mainly of unfossiliferous yellow and white sands. A typical section of these beds may be seen at the sand quarry where a basal white, brown, yellow and red mottled friable sandstone band is overlain by white and yellow sands showing some banding. (Sample A186). In the upper parts of this section there is a yellow, hard limonitic (in part) sandy band, the thickness of the formation being 10½ feet. The only fossiliferous arenaceous limestone occurring in this division of the succession is a capping over the small hill between the Canyon and Bennett's Creek. This bed is hard, white with some yellow staining and travertinous in appearance (Sample A175). It is slightly fossiliferous, 4 feet thick and overlying 6 feet of yellow sands (Sample A176).

2. This division extends from 120 yards south of the spur below the trig. point to the north side of Blanche Point. A typical section is described from above "Uncle Tom's Cabin": yellow sands (Sample A200) 9 feet thick are overlain by a green clayey sandy bed (A199c) grading into a dark grey, green to brown clay (A199b) 4½ feet thick, capped by white sandy limestone (A199a) 5½ feet thick. This upper limestone is slightly fossiliferous, and towards the north of this division it is slightly pebbly; the underlying 12 feet of sands in this position also contain pebbly bands.

The top of the upper hard limestone forms an intermediate platform between beach level and the top of the cliffs. This hard band, however, does not seem to extend to the base of the ? Pleistocene clays in the northern parts of this division, where grey to white pebbly sands (Sample A197) pass upwards into yellow sandy clays (A196) and yellow clays (A195). The transition is exposed in a small stream course, and the clays here pass directly upwards into a grey mottled bed (A194) which grades up into red ? Pleistocene beds. The formation as described (*i.e.*, above "Uncle Tom's Cabin") is the same in the southern limits of this division. There are, however, calcareous nodules in the basal parts here, which are similar in appearance to some which occur at the base of the Pliocene along the north side of Blanche Point. A feature of interest is the so-called "sandstone dyke" which occurs on the path from "Uncle Tom's Cabin" to the top of the ? Pleistocene. This is a "dyke" in appearance only, formed by the lower sands

of the formation which have filled in a crack in the underlying Pre-Pliocene beds and become cemented to form a sandstone.

3. The third division may be seen from Blanche Point to south of Snapper Point almost to the huts at Aldinga Beach. Generally the beds are as follows: Basal beds of highly fossiliferous yellow sands overlain by white sands with irregular bands and lenses of calcareous sandstone and arenaceous limestone are capped by 5 feet of white to grey arenaceous limestone with sandy lenses, the whole being approximately 18 to 20 feet thick. The section is generally fossiliferous, more so at the base and in the irregular bands where mostly casts only are to be found. Some fossils are to be found in the white sands and fossil impresions and casts are to be seen with some occasional fossils in the upper hard white limestone. In places a greenish sandy clayey bed, best seen in Chinaman's Gully, underlies this upper hard white limestone and there is evidence to suggest that there is an unconformity below this latter bed. A typical section may be seen along the road leading to the jetty at Port Willunga, and this is described hereunder:

Top	
White fossiliferous arenaceous limestone	5'0"
Yellow to white mottled sand	2'0"
Hard calcareous sandstone with some fossils	1'8"
White sand	1'0"
Hard calcareous sandstone with fossils	1'0"
White sand	1'0"
Hard arenaceous richly fossiliferous limestone	2'0"
White fossiliferous sand	9"
Yellow sand with hard sandstone leaf	2"
White sand	8"
Hard arenaceous fossiliferous limestone	1'6"
Yellow to white mottled sands, richly fossiliferous	9"
Hard fossiliferous nodular limestone	6"
	18'0"

Boulders of Pre-Pliocene formations are occasionally found at the base of the Pliocene beds and white chalky nodules are also found in the coloured beds immediately underlying the topmost arenaceous limestone. The top of this formation is exposed between Snapper Point and the huts at Aldinga Bay as a fossil erosion surface.

Fauna—

FORAMINIFERA: *Elphidium* species are prominent but have not been separated. *Marginopora vertebralis* Quoy and Gaimard is common in the hard limestone bands. (Samples A163, A165).

LAMELLIBRANCHIA: *Ostrea arenicola* Tate, *Spondylus spondyloides* (Tate), *"Pecten" consobrinus* Tate, *Chlamys asperrimus antiaustralis* (Tate), *Tellina lata* Quoy and Gaimard, *Dosinia (Kereia) greyi* Zittel, *Pinna* sp. (b), *Spisula variabilis* (Tate).

Tate lists these additional species: *Placunanomia ione* Gray, *"Pecten" palmipes* Tate, *Amussium lucens* Tate, *Pinna semicostata* Tate, *Glycimeris convexus* Tate ("imperfect specimens"), *Trigonia acuticostata* McCoy ("casts probably of this species"), *Cardita trigonalis* Tate, *Lucina araea* Tate, *L. nuciformis* Tate, *L. fabuloides* Tate, *Loripes simulans* Tate, *Lepton planuisculum* Tate, *Cucullaea corioensis* McCoy, *Crassatella oblonga* (Tenison-Woods), *Pecten subbifrons* Tate, *Limatula jeffreysiana* (Tate), *Meretrix sphericula* Basedow ("large imperfect cast referable to this species").

Gastropoda: Casts of *Potamides* sp., *Cerithium* sp., *Phasianella* sp., *Terebra* sp., *Cassis* sp., ? *Architectonica* sp., *Bulinella* sp., and casts and external moulds of *Haliotis* sp. have been seen.

Tate lists these additional fossils: *Trophon anceps* Tate, *Lampusia sexcostata* Tate, *Cominella subfilicea* Tate, *Latirus approximans* (Tate), *Ancilla orycta* Tate, *Terebra mitrellaeformis* Tate, *Terebra crassa* Tate, casts of *Cassis textilis* Tate, *Natica subvarians* Tate, *Capulus danieli* Crosse, *Rhinoclavis subcalvatus* (Tate), and the Scaphopod *Cadulus acuminatus* Deshayes.

Echinoideas *Peronella platymodes* (Tate), and others.

Crustacea: Ostracodes, crab claws.

Whilst casts of fossils are common in the lower beds of the formation, shells are also plentiful and, in particular, *Ostrea arenicola*, *Spondylus spondyloides*, "*Pecten*" *consobrinus*, and *Chlamys asperrimus antiaustralis* are abundant. These beds are sometimes referred to as "Oyster Banks".

Contacts—The formation overlies the Pre-Pliocene formations with angular unconformity and is overlain by the ? Pleistocene beds. Where the ? Pleistocene beds directly overlie sands, the upper contact is not always well defined.

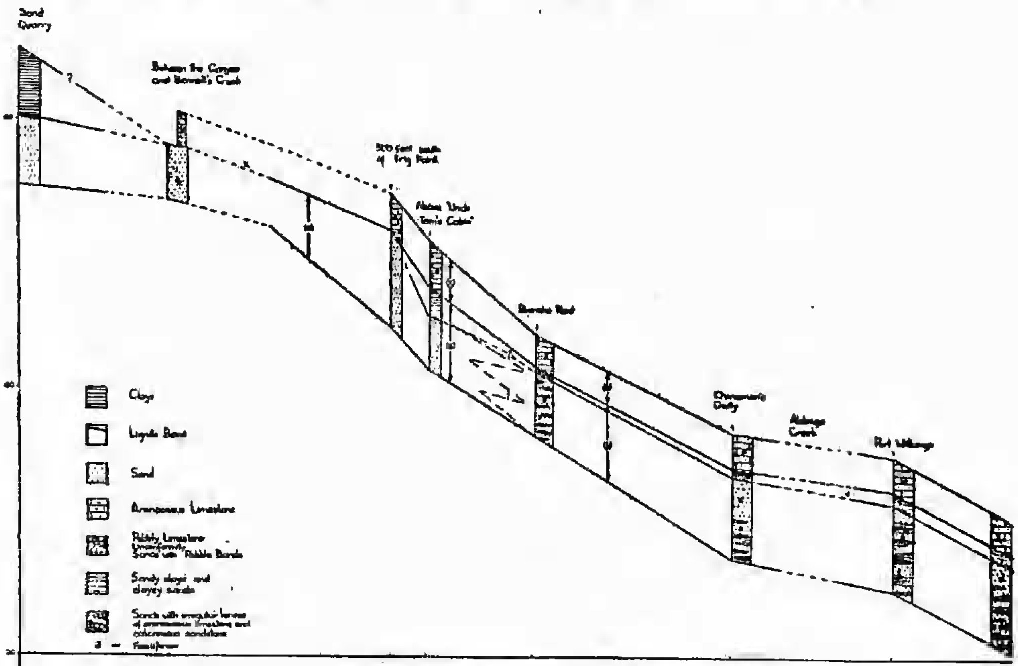


FIG 3 : THE CORRELATION OF THE PLIOCENE BEDS

Thickness—The maximum thickness by measurement varies from 18 to 20 feet.

Remarks—This formation could possibly be divided into three members, viz: (a) Non-marine Sands, (b) First Marine Beds and (c) Second Marine Limestone, (see Fig. 3). The subdivision is based on these facts:

(a) the sands from north of Ochre Point to north of Blanche Point are unfossiliferous, they are capped by limonite (? lateritic) to the north and just below the trig point they have pebble and gravel bands. Such properties suggest a terrestrial environment. In addtion to these may be quoted the occurrence of a silty bed containing lignitic material at the top of Pliocene sands at the sand quarry. It underlies a brown limonitic bed and dark brown-green clays which may be Pliocene or ?Pleistocene in age, and overlies a con-

solidated sandy bed highly perforated by roots. In view of available facts, *i.e.*, the limonitic capping to these sands further south, the clay occurring above the sands above "Uncle Tom's Cabin" and pieces of wood from this locality, the lignite band is tentatively classed as Pliocene.

(b) The first marine series includes the lower sands, sandstones and limestones described under Division 3. These are highly fossiliferous and in contrast to the non-marine beds described under (a) above. The sandy clayey bed at the top of these beds may possibly be equivalent to the clays at the top of the non-marine beds above "Uncle Tom's Cabin." Any transition from a non-marine to a marine environment will be exposed along the north side of Blanche Point but these beds are inaccessible.

(c) The upper limestone described under Divisions 2 and 3 (Lithology) appears to overlie the basal non-marine and marine sands with unconformity. It appears to be approximately uniform in lithological nature and, although assumptions can only be made in general on casts of fossils, the faunal assemblage seems to differ at least in part from the assemblage of the first marine beds. The outlier of Pliocene limestone occurring between Bennett's Creek and the Canyon is tentatively placed with this member. It has the same travertinous appearance and is poorly fossiliferous, casts only having been seen.

UNIT NO. 8: ? PLEISTOCENE AND RECENT DEPOSITS

The ?Pleistocene beds are exposed from north of Ochre Point to South of Snapper Point and consist predominantly of red mottled sandy clays overlain by green sandy clays. Boulder and gravel beds were noted in the red beds at Ochre Point but generally the composition of the beds is as described above. South of Blanche Point the lower red beds have been covered by the overlying green beds and are no longer visible. A thickness of 10 feet of brown to green clays underlies the red beds in the northern parts of the succession but it is not certain whether these beds belong to the Pliocene non-marine member or ? Pleistocene. The maximum thickness of ? Pleistocene beds as measured between the trig. point and "Uncle Tom's Cabin" is 59 feet, of which the red beds form 39 feet. From Blanche Point to Chinaman's Gully, these beds gradually become thinner but from Port Willunga to Snapper Point they again approach the maximum thickness, and at Snapper Point are approximately 55 feet thick. These beds cannot on available evidence be classed definitely as Pleistocene.

Angular unconformity between Pliocene and Pre-Pliocene beds may be seen from approximately one-third of a mile north of Blanche Point to just north of Snapper Point. It is also seen in the southermost quarry cutting where the contact between the white sands and the overlying brown and green sands is truncated by almost horizontal sands, the significance of which is discussed below. This unconformity dips from a height of approximately 90 feet in the vicinity of the sand quarry to sea level just north of Snapper Point, (i.e., approximately 30 feet per mile).

The Pliocene-?Pleistocene contact is well defined from Blanche Point to just north of the huts at Aldinga Beach where an erosion surface is exposed on the uppermost limestone of the Pliocene beds. North of Blanche Point, however, the upper limestone bed is not continuous and the base of the ?Pleistocene occurs directly above sands for most of the distance. Under such conditions the break between Pliocene and ?Pleistocene is not well defined and there appears to be an intermixing of the upper Pliocene sands with the basal beds of the ?Pleistocene deposits. This contact has a similar dip to the angular unconformity and from a height of approximately 100 feet to the north of the succession, it reaches sea level at Snapper Point as the erosion surface mentioned above.

Recent deposits include a thin layer of kunkar, which, in general, is continuous and overlying the ? Pleistocene beds. However, it does overlie other beds as mentioned hereunder in the discussion of the creeks. A thin layer of topsoil is seen in parts of the section, whilst also included under Recent deposits are the aeolian and other deposits which, particularly in the embayments, obscure some parts of the lower beds in the coastal section. The three creeks which traverse the coastal section at the Canyon, Bennett's Creek and Aldinga Creek are believed to have been much deeper at some time between the completion of deposition of the ? Pleistocene beds and Recent times. At the Canyon, in the northern wall, the ? Pleistocene beds are no longer divisible into two divisions and seem to have been reworked. The North and South Maslin sands exposed in the southern wall have likewise, in part, been resorted to form a bed of pebbles and coarse white sand overlain by a conglomeratic deposit with pebbles of limonite and quartzite in sand beds. This formation is in complete contrast to the exposure at the westernmost portions of the southern wall, where the North Maslin Sands are exposed beneath a thickness of approximately 30 feet of South Maslin sands in an unaltered condition. The northern wall shows only the resorted ? Pleistocene beds, and these are overlain by Recent sands which extend to the top of the small hill immediately north, where only small outliers of the kunkar remain above Pliocene and ? Pleistocene deposits. Silicified roots are to be seen in some abundance in these sands.

At Bennett's Creek the ? Pleistocene beds are not to be seen within 150 yards either north or south, and Recent sands and deposits form gradual inclinations on both sides. Just south of Bennett's Creek, the South Maslin sands have been cemented to form a hard rock at the surface. Just north and south of Aldinga Creek the old creek bed may be seen cutting the section. The overlying ? Pleistocene beds have been removed and the thin kunkar layer directly overlies both Pliocene and Pre-Pliocene beds, and in the south it may be seen resting above the fluvial deposits of the former creek. The Pre-Pliocene beds appear to fold downwards beneath these deposits, and this can be accounted for by a slumping of the upper incompetent beds when lower beds have collapsed due to erosional forces. An erosional surface, similar to the type seen south of Snapper Point, was observed just north of Port Willunga at beach level above the fluvial sediments, which are predominantly dark in colour and contain pebbles of kunkar which define bedding. Evidence of a submergence of the present coastline in comparatively Recent times may be seen in the form of terraces in the vicinity of Bennett's Creek. These consist of boulder and pebble beds which occur above the present beach level associated with deposits of Recent types of shells, including *Turbo undulata* Martyn and the common limpet *Cellana tramoserica* (Martyn). On the other hand, these may be storm beaches or such shell deposits may have been formed by wandering tribes of aboriginals who have been known to pass through this vicinity and who leave such remains at their squats. Definite emergence of the coastline, however, seems probable in view of the stream profiles earlier discussed. Certain terms such as "raised sea-beaches" have been purposely avoided in this discussion and definite conclusions regarding changes in sea-level have not been formed in view of the fact that it has not been possible to carry out detailed studies.

IV CONDITIONS OF DEPOSITION

The North Maslin sand deposit is probably deltaic and may have originated from adjacent Precambrian quartz-rich sediments. Gravel and coarse sediments are usually not common in deltaic deposits, except where streams flow into a sea or lake directly from uplands, when gravel may become a considerable part of

the sediments. Clay bands with and without plant remains and cross-laminations are also suggestive of deltaic deposits. The quartz boulders and pebbles at the base of the sands are probably derived from two sources, the more angular being from adjacent Precambrian uplands and left as relics of an original piedmont deposit, whilst highly polished pebbles have probably been accumulated by the resorting of the underlying ? Permian beds, the till being removed by distributaries to possibly form "bottomset"[2] beds. Determination of "subaerial" and "subaqueous", "topset" and "foreset" beds has not been possible in view of the relatively small size of this deposit as compared with the large areas usually covered by deltaic deposits, and because it has only been possible to examine this exposure more or less as a vertical section.

There is evidence to suggest that there is a transition between the non-marine sands and the overlying South Maslin sands. As already mentioned, there is a brown bed with quartz pebbles 3 feet above the base of the latter, and this is considered as being deposited by terrestrial agents. Twenhofel, in his discussion of "sediments of the foreset slope," says: "Certain chemical sediments, such as glauconite, may also form," and in view of the cross-bedding which is in part similar to that exhibited by the North Maslin sands, it is suggested that these beds are closely associated with the deltaic environment. The units formed in the brown sands are, however, generally more lenticular than those in the white sands. The cross-laminations of the South Maslin sands are produced mainly under a marine environment in contrast to those of the sand quarry deposit. It has already been proposed that some of the limonitic grains have been formed by the alteration of glauconite, but it is not within the scope of this paper to discuss the formation of the latter mineral. The limonitic bands exposed in cross-laminations are not regarded as of the same origin as the grains formed by alteration of glauconite. They form the capping to units in the lower parts of this formation, and are probably the result of precipitation of colloidal clay and iron oxide, ". . . . and there may also be much precipitation of colloids of iron oxide and silica where fresh and salt waters mingle" (Twenhofel, 1950). This would also explain their somewhat laminated nature. Mudcracks with the intervening limonite being sometimes curved concavely upwards or peculiarly coiled could be formed in this near-shore environment. Only some of the limonite grains can be acconted for by the alteration of glauconite and the remainder may be attributed to a precipitation from colloids, followed by dispersal amongst quartz sands by weak wave or current action. Iron oxides derived from the chocolate shales underlying the Precambrian quartzites, etc., at Ochre Cove, could be the source of much of this limonite. At the furthermost limits of this formation from the sand quarry, the sands are predominantly limonitic and the limonitic capping is no longer observed. The mingling of fresh and salt waters would be less marked at this distance from the landmass, and the percentage of grains formed from glauconite would be greater in deeper neritic seas. Macrofossils are found mainly in lenses of a light-green to purple colour, and these may be part of the "foreset" environment (Twenhofel states that "shell matter should be more or less abundant over foreset bottoms, particularly between distributary currents . . . .").

Erosion occurred before the next group of beds was formed, and a disconformity separates the South Maslin sands and the Tortachilla Limestones. The latter are richly fossiliferous and are rich at the base in limonite grains derived from the underlying formation, and polyzoa. The character of the fauna

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[2] The terms used in this discussion of deltaic deposits and such statements as are made in support of a deltaic environment are taken from Twenhofel "Principles of Sedimentation" Second Edition, 1950, p. 102-118. Such terms and statements have been included in quotation marks.

which is mainly benthonic with some planktonic forms, is indicative of a shallow water environment. These are autochthonous limestones which generally have little or no clastic detritus and it is suggested that they were formed in clear water with little wave action. Above the less consolidated, limonitic, polyzoal sands they become very hard, although there are softer pockets of glauconitic clay in the upper parts. Sedentary organisms may have played a major part in the formation of these beds, in which case the limestones could be regarded as a biostrome formation. It would seem from the transition of the purely polyzoal limestone to glauconitic limestone that the latter can be formed gradually without materially changing environmental conditions. However, there must be the addition of material from which such glauconite can be formed, and in the absence of biotite flakes, in view of the composition of the directly overlying marls, it is contended that a certain amount of clay, probably in colloidal form, has been deposited at the same time as the upper parts of the biostrome were being formed.

As the amount of clay deposited became greater, a new sediment was formed, which was also quite rich in $CaCO_3$, a fair percentage of this being contributed by the tests of micro-organisms, mainly foraminifera. There is a transition, therefore, from the glauconitic limestone to a glauconitic and limey marl, the basal formation of the Blanche Point Marls. Above the transitional marls are hard and soft bands of calcareous, and in part siliceous sediments which are essentially marls in composition. Silica is contributed in the main by sponge spicules, which become comparatively abundant. The sponges which predominated are of the tetractinellid and monactinellid rather than hexactinellid type, and these are generally more common in shallow warmer waters. The tests of *Turritella aldingae* are plentiful in these and the overlying soft marls, and their abundance is marked in the upper banded marls, where they may be seen deposited at random. One would have expected a set pattern of arrangement for these tests had there been any distinct movement of water. Further evidence for suggesting calm waters is given by the flat nature of exposed surfaces as seen south of Blanche Point, and also by the discovery of paired Lamellibranch valves and an Echinoid with some spines still attached. There seems to be little change in the conditions of deposition from the earlier deposition of the Polyzoal limestone to the final stages of deposition of the Blanche Point Marls, the marine environmental conditions of relatively shallow clear waters, with little movement persisting throughout. Parr, as mentioned by Glaessner (1951) found that "all the beds at Port Willunga and Maslin Bay were laid down in much shallower water than the Brown's Creek and Hamilton Creek beds. . . . In all of the samples I have looked at there is an almost complete absence of pelagic forms and species of the Polymorphinidae are very common." However, the height of sea-level relative to the base level of deposition may have changed during the deposition of the *Limopsis* bed at the top of the Soft Marls. Here foraminifera are not abundant and are relatively very small, whilst large numbers of *Limopsis* are found with *Chione*, some *Turritella* and other mollusca, the pellets of such being abundant. This distinctive biofacies found only in this horizon is thought to represent a different environment.

Following the marine phase, there are beds which have been deposited under a terrestrial environment. An erosion surface may have existed as previously explained by the presence of white nodules at the top of the marls and the second non-marine series is generally unfossiliferous, such fossils as are found being few in number and probably derived from the underlying formation, *i.e.*, remanié fossils. This formation, the Chinaman's Gully Beds, is variously coloured from grey-blue silts to red and brown clayey gritty beds, it is in part cross-bedded and shows Liesegang rings. These deposits also resemble a small deltaic deposit formed

under arid conditions. This formation is only 5 feet thick and overlain by the Port Willunga Beds. The base of these latter beds consists of a green bed 1½ feet thick, rich in arenaceous foraminifera and with some limonitic grains. The faunal assemblage is peculiar and may possibly represent a brackish water facies. The environment thereafter is again marine, and, whilst the faunal assemblage and the nature of the sediments indicate shallow water conditions, there is evidence to suggest that these deposits were more affected by wave and current action, due to the fact that the tops of beds seem to be frequently levelled by erosion. Cross-bedding is common, polyzoal remains being commonly prominent in cross-bedded sediments. Foraminifera are mainly shallow water types, and some appear to be adapted to attachment, being characterised by flat or concave surfaces.

The beds described above belong to the Pre-Pliocene formations and have a slight dip generally less than 3° in directions which although variable are, with the exception of the base of the North Maslin Sands, confined to a south-west to south-east direction. These beds, originally horizontal, have been tilted by the tectonic movements of late Miocene age.

Pliocene beds have been discussed in some detail, and the conditions of deposition with reasons for the assumptions made are mentioned under Formation 7. Shallow seas formed part of this succession at least as far north as the Canyon towards the end of the Tertiary period. The ? Pleistocene beds are widespread, and whilst they have been obviously deposited under a terrestrial environment, little more can be said concerning conditions of deposition until they have been studied in more detail.

V STRATIGRAPHIC REMARKS

1. *Ranges of Fossils.* Some detailed work has been commenced in the study of the Foraminifera from various horizons and some macrofossils have been named, and their ranges throughout the succession noted, but it will not be possible to draw any conclusions until more work has been done. *Hantkenina alabamensis* and the significance of its discovery in the basal beds of the Blanche Point North Transitional Marls has already been discussed. *Sherbornina* is confined to the limits of the Port Willunga Beds. Certain macrofossils have ranges which appear to be restricted and some of these have been listed in Table II.

Fossils not listed in the table but which may prove to be important include: (1) *Notostrea lubra,* which has been found mainly in fallen blocks, but is probably restricted to the Blanche Point Transitional Marls and the basal members of the overlying Banded Marls: (2) *Aturia,* which was found by Dr. Glaessner three feet above the base of the South Maslin Polyzoal Limestone and has not been found elsewhere; *Nautilus* remains seem to be common in the Banded Marls; (3) *Marginopora vertebralis* is found in the marine Pliocene beds, more so in the upper limestone, member (c). An occurrence of interest is in the cross-bedded Polyzoal limestone at the base of the Port Willunga Beds, sample No. A113, where there is an abundance of barnacle remains, which do not appear elsewhere in the succession.

2. *Sequence of Strata.* The "Glauconitic Marls with *Hantkenina*" (Glaessner 1951) are equivalent to my Blanche Point Transitional Marls, and the beds which underlie this Member are not younger than Upper Eocene.

Although the North Maslin Sands are a non-marine formation there is evidence of a transition between them and the overlying South Maslin Sands. Since these latter beds appear to have been eroded before deposition of the overlying Tortachilla Limestones, it is suggested that the South Maslin Sands are to be regarded as Lower Eocene, the North Maslin Sands as basal Tertiary, and

the Tortachilla Limestones which pass with transition upwards into the Blanche Point Transitional Marls are probably Middle to Upper Eocene in age. Conformably above the Transitional Marls are the Blanche Point Banded Marls ("Turritella Marls," Glaessner 1951) and the Blanche Point Soft Marls ("Turritella Clays of Aldinga Bay").

TABLE II

	Formation	3		4			6	7	
Fossils	Members	A	B	A	B	C		B	C
Echinolampas posterocrassus		x							
Australanthus longianus		x	x						
Eupatagus sp.		x	x						
Chlamys flindersi			x	x	?				
Notostrea tatei			x						
Spondylus sp.					x				
Turritella aldingae					x	x			
Flabellum distinctum					x				
Lentipecten sp.						x			
Lentipecten cf. *victoriensis*						x			
Propeamussium atkinsoni					x	x			
Limopsis chapmani						x			
Ancilla ligata						x			
Voluta pagodoides						x			
Trivia avellanoides					x	x			
"Pecten" eyrei							x		
"Pecten" cf. *consobrinus*							x		
Chlamys asperrimus asperrimus							x		
Ostrea arenicola							x	x	
Duncaniaster australiae							x		
Linthia compressa							x		
Graphularia senescens							x		
Spondylus spondyloides								x	
"Pecten" consobrinus								x	
Chlamys asperrimus antiaustralis								x	
Spisula variabilis								?	x
Peronella platymodes								x	

Glaessner (1951) suggests that the age of these beds is Oligocene. In view of the conformable nature of these Formations, this suggestion seems to be justified and it will be possible to verify it as foraminiferal research proceeds. The Chinaman's Gully Beds ("Red Sands") have been mentioned as possibly overlying an erosional surface, and because there appears to be a transition between them and the overlying Port Willunga Beds ("Polyzoal Beds of Aldinga Bay"), it is suggested that they should be regarded as closer to the latter than to the underlying Marls.

The Pliocene Limestones ("Upper Aldingan") lie with angular unconformity over the formations discussed. Glaessner places these limestones with the "Upper Murravian" in the Lower Pliocene (Kalimnan). Whether its tentative local subdivision outlined above is justified will remain uncertain until the outcrops have been studied in greater detail. Likewise, the age of the ? Pleistocene and Recent deposits will remain in doubt until further research has been carried out.

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